Environmental Effects of Dredging
Technical Notes

Vertical Strip Drains to Increase Storage Capacity of Confined Dredged Material Disposal Facilities

Purpose

This technical note describes the use of vertical strip drains for improved management of confined dredged material disposal areas.

Background

Fine-grained dredged material usually enters a confined disposal facility (CDF) in a slurry consisting of 10 to 25 percent soil particles (i.e., 440 > water content > 110 percent). After the slurry spreads over the CDF, the fine-grained material starts undergoing sedimentation. At some point in the sedimentation process, the soil particles begin touching each other and, eventually, a continuous soil matrix is created. From this condition, the settlement of the surface of the matrix is determined by the densification of the soil matrix. Densification is governed by a process called primary consolidation. At the start of primary consolidation, the soil matrix is extremely soft and usually has a void ratio of 10 to 20 and a saturated unit weight of 10.2 to 11.8 kN/m^3 (65 to 75 pounds per cubic foot).

Excess pore water pressures are induced in the soil matrix by the weight of overlying dredged material creating pressures in excess of the hydrostatic water pressures. The primary consolidation process through which excess pore water pressures are dissipated involves forcing water from the soil matrix. Once the excess pore water pressures have dissipated and consolidation is completed, a hydrostatic condition is established in which no further flow or primary consolidation occurs.

Relationships describing the one-dimensional consolidation process, as developed by Terzaghi (Terzaghi and Peck 1967), show that the rate of consolidation

(rate of settlement of the surface of the soil matrix) is a function of the ratio C_V/H^2_{dr}, where C_V is the coefficient of consolidation and H_{dr} is the length of drainage path. The total amount of consolidation (settlement of the surface) that a soil mass can experience is a constant; however, the rate of consolidation can be increased by increasing the value of C_V or by decreasing the length of the drainage path. Suffice it here to state that decreasing the drainage path is much easier than increasing the value of C_V. Note also that if the length of drainage path is halved, for example, the rate of consolidation is increased by a factor of four. The main objective of installing vertical strip drains in a confined dredged material management area is to reduce the length of the drainage path.

As pore water is expelled from the soil matrix, the volume of the matrix decreases, causing a settlement of the surface and thereby increasing the storage capacity and soil shear strength, both desired effects. The main purpose of installing vertical strip drains in a confined dredged material management area is to reduce the length of the drainage path, thereby accelerating the primary consolidation process.

Additional Information

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Introduction

In the last 5 to 10 years, vertical strip drains have replaced conventional sand drains as the preferred method to accelerate the consolidation of soft cohesive soils. Most strip drains are modeled after the cardboard strip drain developed by Kjellman (1948). Strip drains are band-shaped and have a rectangular cross section approximately 100 mm wide and 4 to 5 mm thick. A plastic core with grooves, studs, or channels is surrounded by a filter fabric. The filter fabric is most commonly a nonwoven geotextile that prevents soil particles from entering and clogging the core. The core carries expelled pore water to the dredge fill surface or underlying drainage layer.

Vertical strip drains have been used in many projects throughout the United States to accelerate consolidation of soft cohesive soils, including the recent expansion of the Port of Los Angeles (Jacob, Thevanayagam, and Kavazanjian 1994), the Seagirt project in Baltimore Harbor (Koerner, Fowler, and Lawrence 1986), the construction of dredged material containment areas in the Delaware River near Wilmington, DE (Koerner and Fritzinger 1988, Fritzinger 1990), and the New Bedford Superfund site near New Bedford, MA (Schimelfenyg, Fowler, and Leshchinsky 1990).

Strip drains arrive at the site in large rolls and are installed using a hollow mandrel (Figure 1). The end of the strip drain is threaded down the inside of the mandrel, which must be as long as the depth to which the strip drains are to be installed. At the bottom of the mandrel, the strip drain is threaded through a baseplate and inserted into the mandrel (Figure 2). The baseplate is used to keep the strip drain at the bottom of the mandrel (to prevent soil from entering the mandrel during the insertion process) and to keep the strip drain
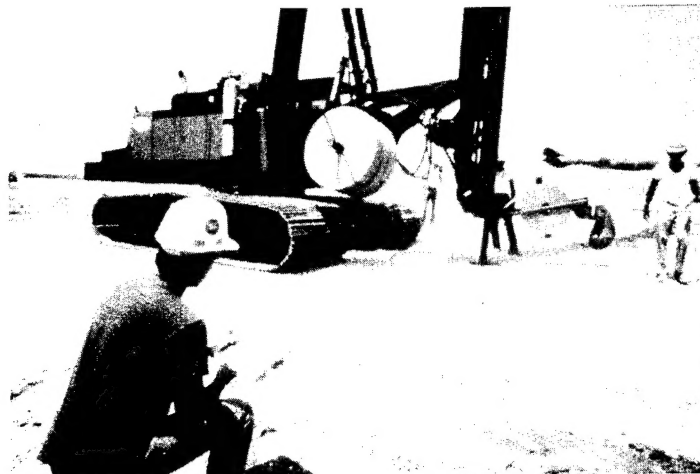

Figure 1. Typical vertical strip drain installation equipment

Figure 2. Vertical strip drain installation procedure

at the desired depth as the mandrel is withdrawn. When the mandrel is withdrawn from the ground, the strip drain is cut, and the process is repeated at the next location. This insertion cycle is rapid (1 to 3 min) and only the strip drains, baseplates, and a cutting tool are required.

Use of Vertical Strip Drains at Craney Island Dredged Material Management Area

The Craney Island Dredged Material Management Area (CIDMMA) is a confined disposal facility (approximately 8.9 km^2) located near Norfolk, VA. Dredged material has been placed in the management area almost continuously since construction of the original dikes was completed in 1957. The facility was initially designed to store 76.4×10^6 m^3 (100×10^6 yd^3), which at the time was thought adequate for a 20-year period of operation.

Increased dredging in the Norfolk channel has required the capacity of the CIDMMA to be increased by raising the dikes on three separate occasions. The dikes were raised from elevation +2.4 to 5.2 m mean low water (mlw) in 1969, to elevation +7.9 m mlw in 1980, and to elevation +10.4 m mlw in 1988. The final dike raising required the placement of an underwater stability berm (305 m wide) along the outer toe of the west perimeter dike and large dike setbacks along the north and east perimeter dikes to ensure stability of the perimeter dikes (Figure 3). The dike setbacks are usually 60 to 90 m, which results in approximately 0.08 to 0.12 km^2 of lost storage capacity during each dike raising.

Interior dikes were built within the CIDMMA to create three containment areas. This design improves sedimentation in the compartment being filled, while allowing the dredged materials in the other two compartments to desiccate and consolidate faster. The removal or evaporation of surface water accelerates the desiccation and increases the amount of consolidation because the effective density of the soil increases as the pore water evaporates. Construction of the interior dikes was completed in 1983. On the average, 3 to 3.8×10^6 m^3 of dredged material is placed in a compartment each year. Dredging results in a net increase in dredged fill thickness of 1 to 2 m per year in each compartment being filled.

After the dikes were raised for the third time, the U.S. Army Engineer Waterways Experiment Station (WES) conducted an extensive consolidation and desiccation analysis to predict the remaining service life of the CIDMMA (Palermo and Schaefer 1990). This study was conducted using the 1989 version of the microcomputer program entitled Primary Consolidation and Desiccation of Dredged Fill -PCDDF89 (Stark 1991) and revealed that the current capacity of the CIDMMA will be exhausted near the year 2000. Because the perimeter dikes are at their maximum height (as controlled by the stability of the foundation) and the CIDMMA cannot be expanded or replaced (based on a ruling by the Virginia State Legislature), new techniques were sought for increasing its storage capacity.
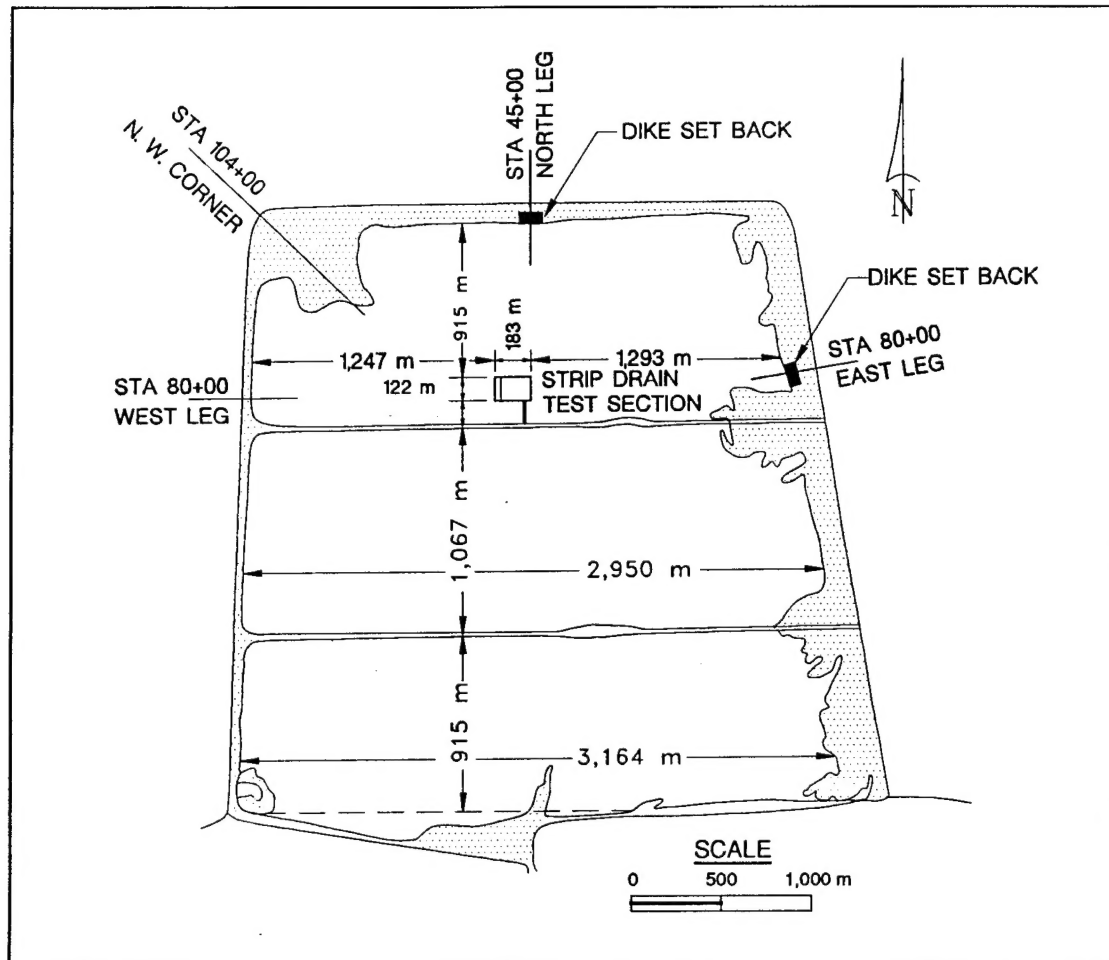
Figure 3. Plan view of Craney Island and location of vertical strip drain test section

Piezometers installed in the perimeter dikes at CIDMMA revealed that large excess pore water pressures exist in the underlying dredged fill and soft foundation clay. In February 1991 the excess pore water pressures in the foundation clay along the west perimeter dike typically exceeded the ground surface by 6 to 8 m. Although it was anticipated that excess pore water pressures also existed in the foundation clay underlying the dredged material inside the containment area, piezometers could not be installed to confirm their existence, because of the low shear strength of the dredged material.

Figure 4 shows the generalized subsurface profile at the location of the vertical strip drain test section at Craney Island (shown in Figure 3). The thickness of the dredged material and foundation soft marine clay is approximately 44 m. Therefore, the maximum vertical drainage path is approximately 22 m because the site is drained at the top and bottom of the deposit. Installation of vertical strip drains, as shown in Figure 5, will result in radial flow as well as vertical flow. As a result, the maximum drainage path will be reduced to one half the strip drain spacing instead of one half the compressible layer thickness. This
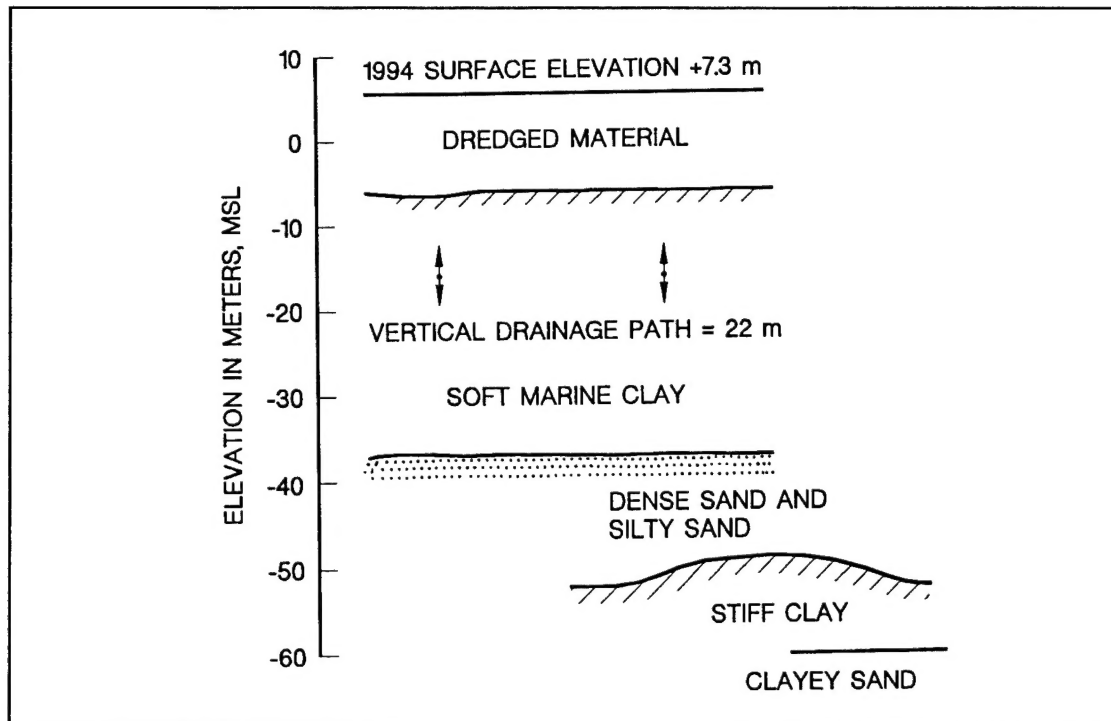
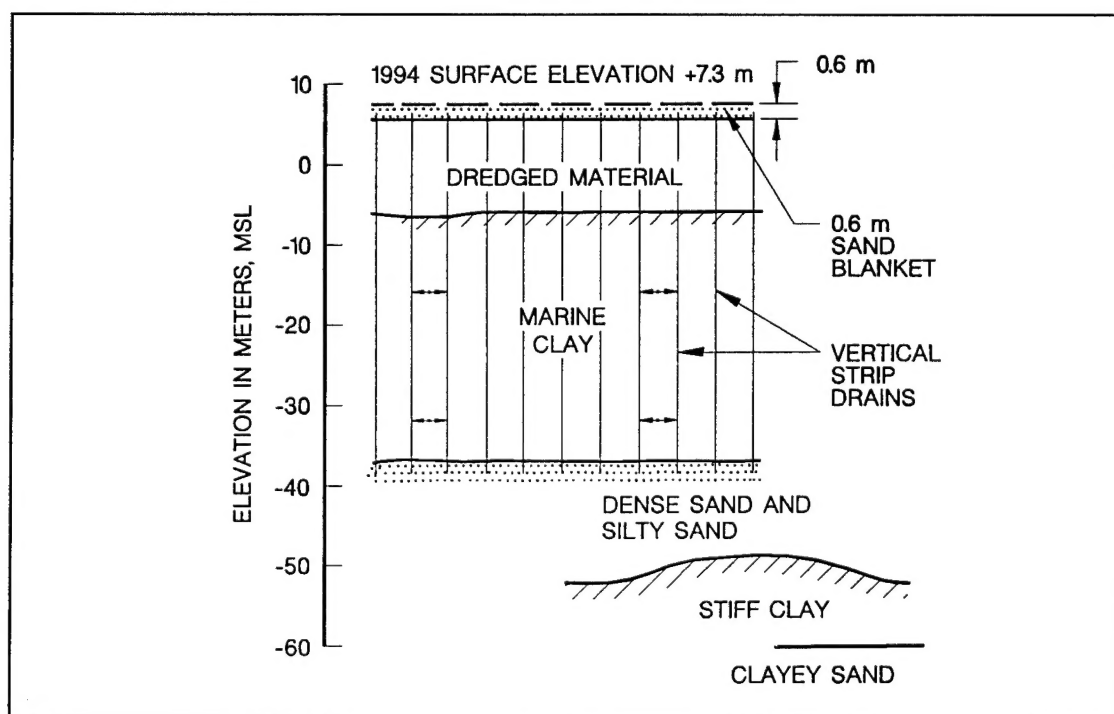Figure 4. Generalized subsurface profile at the Craney Island vertical strip drain test section

Figure 5. Radial drainage pattern using vertical strip drains

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reduction is significant since the rate of consolidation is a function of the squared length of drainage path. The shorter drainage path will result in a substantial reduction in the time required to consolidate the dredged fill and underlying foundation clay.

The recommendation of strip drains to increase the consolidation rate at the CIDMMA was novel for several reasons: strip drains had never been installed in an active dredged material management area; a drain length of 47 to 49 m would be close to the longest drain ever installed (58 m), and the installation equipment could not exert a ground pressure greater than 10.4 kN/m^2. (Typical installation equipment (Figure 1) exerts a ground pressure of 27.6 to 34.5 kN/m^2, which could not be supported by the soft dredged material.) The installed cost of vertical strip drains in the test section was $1.60 to $2.00 per linear meter. The time required for consolidation of the dredged fill and foundation clay is controlled by the spacing of the drains. Therefore, value engineering can be used to determine the optimal spacing of the drains to produce a certain increase in surface settlement, that is, storage capacity, in a specified time.

Effectiveness of Vertical Strip Drain to Increase Consolidation Rates

A field test section was completed in the north compartment in February 1993 to evaluate the effectiveness of vertical strip drains to increase the consolidation rate of the dredged material and foundation clay. The test section was 122 by 183 m (Figure 3) and was divided into two sections. A 0.6-m-thick sand blanket was constructed in the main area (122 by 152 m). A sand blanket was not placed in the mobility test section (31 by 122 m, located on the west side of the test section). The mobility test section was used to determine if the low-ground pressure equipment could operate on the desiccated crust without a sand blanket.

Strip drains were pushed through the dredged fill and foundation clay into the underlying permeable foundation sands. This installation procedure allowed the expelled water to exit the strip drains at the dredged fill surface and into the underlying dense sand.

Settlement plate readings from the main section and mobility section are presented in Figures 6 and 7, respectively. Installation of the vertical strip drains in the test section was completed on February 19, 1993. As of April 6, 1995 (that is, after approximately 775 days), the maximum consolidation settlement in the test section was approximately 2.5 m. Without strip drains, the test section would have settled less than approximately 0.15 m. Therefore, the strip drains are responsible for the majority of the observed settlement. It should be noted that strip drains were installed in the northern portion of the test area first. As a result, the settlement plates in the northern part of the main test section (SP1, SP5, and SP7) show a faster response than the other settlement plates. For example, settlement plates SP1 and SP7 show a significant
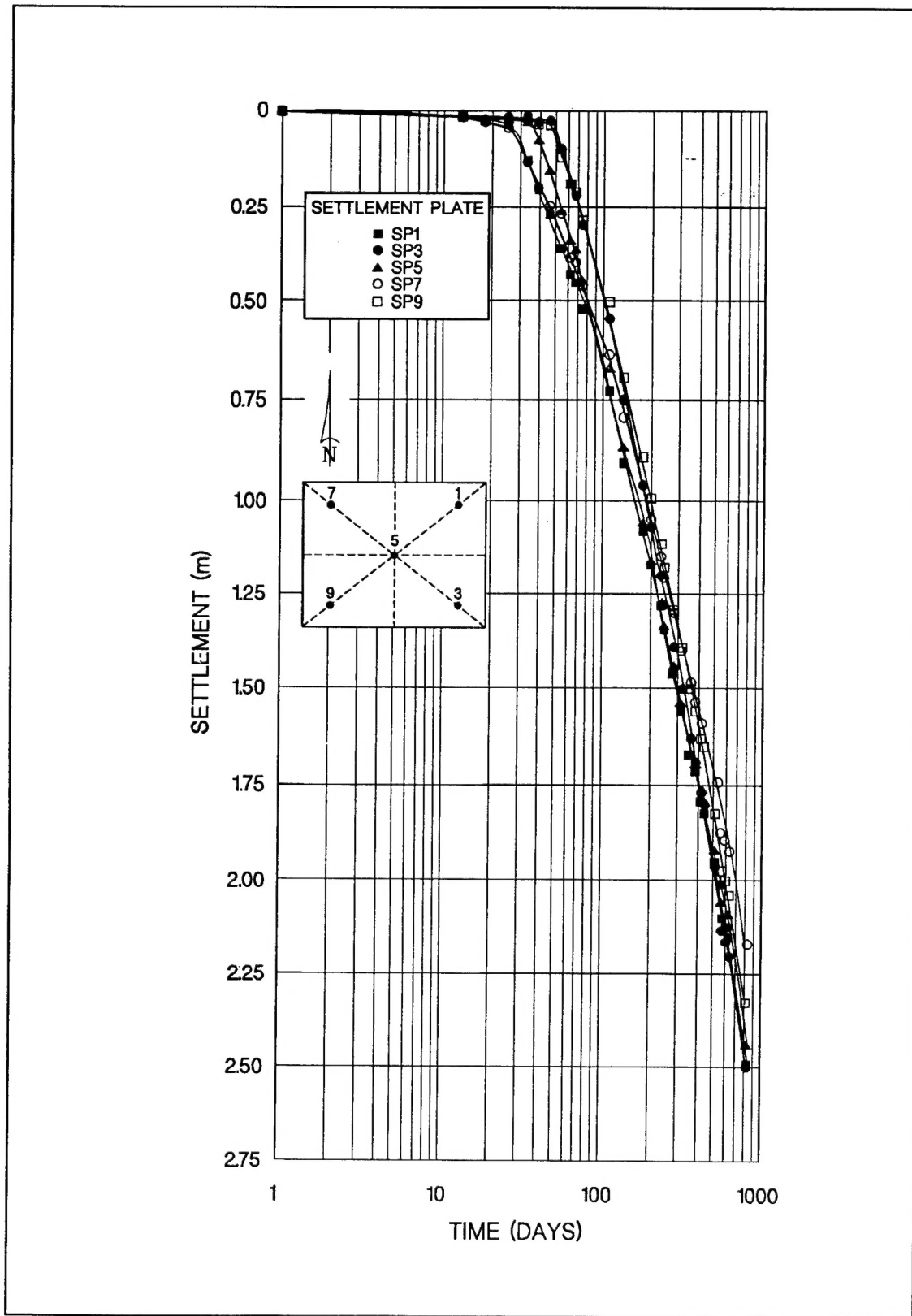
Figure 6. Semilogarithmic presentation of settlement plate measurements
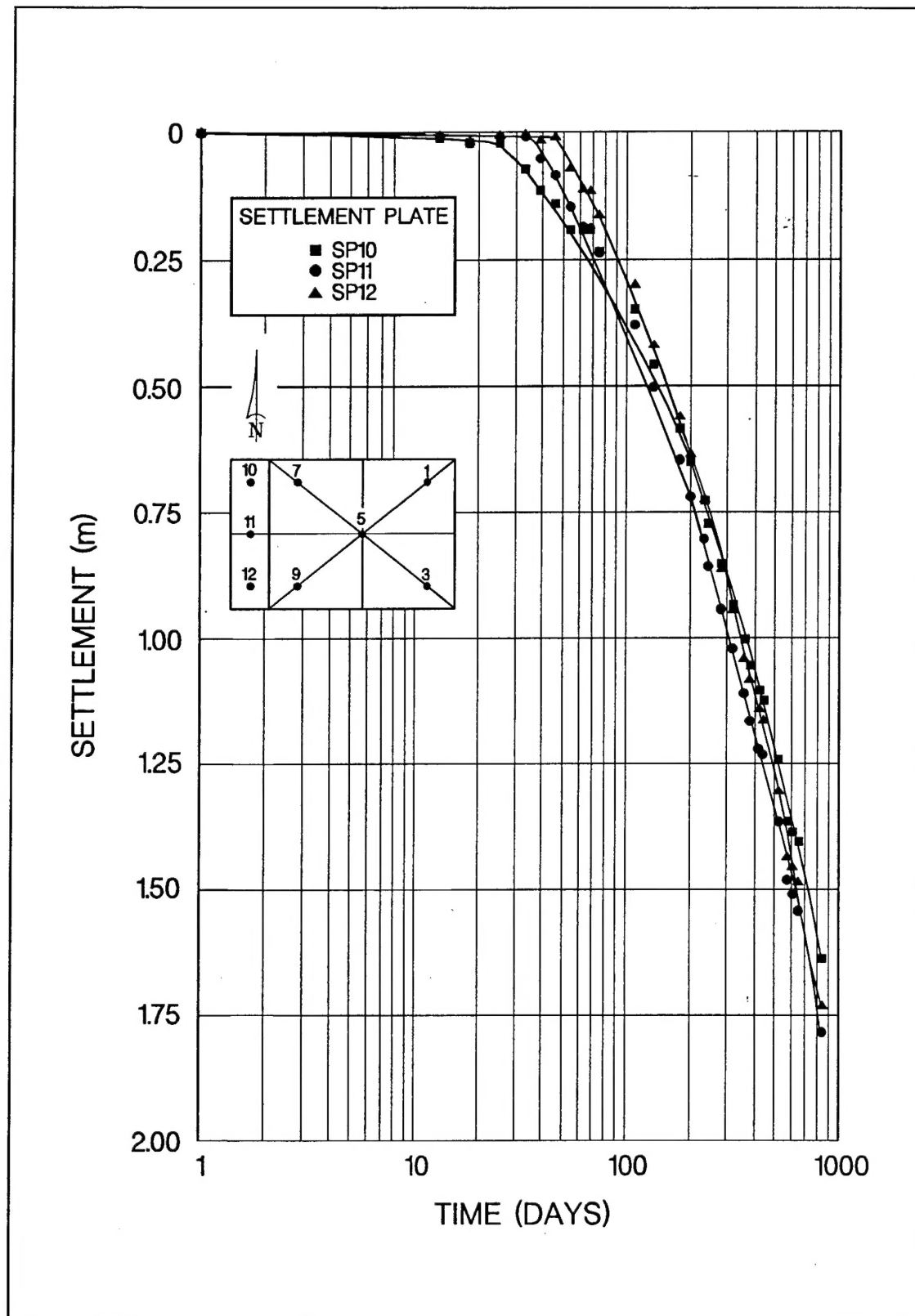in main section

Figure 7. Semilogarithmic presentation of settlement plate measurements
in mobility section

decrease in elevation after only 20 to 30 days. Conversely, settlement plates SP3 and SP9 did not show a significant decrease in elevation until 40 to 50 days after installation of strip drains began.

The end of primary consolidation is identified by a decrease in the slope of the settlement-time relationship. Therefore, as shown in Figures 6 and 7, none of the settlement plates indicates that the end of primary consolidation has been reached, and more settlement should occur in the future.

The mobility section was developed to demonstrate that a sand blanket is not required to support the strip drain installation equipment. A comparison of Figures 6 and 7 provides an insight into the effect of the sand blanket on consolidation of the dredged fill and marine clay. Settlement of plate SP10, located at the northern end of the adjacent mobility section, can be compared with settlement of plates SP1 and SP7 located at the northern end of the main section. Settlement plates SP1 and SP7 have settled 2.2 to 2.5 m, while settlement plate SP10 has settled approximately 1.6 m. Therefore, it can be concluded that the additional surcharge provided by the sand blanket results in a significant increase in consolidation settlement.

Future Research

A technical report describing the vertical strip drain test section, field measurements, and data analysis is being developed by WES. In addition, a microcomputer program that describes Primary consolidation, Secondary compression, and Desiccation of Dredged Fill (PSDDF) is being completed by WES and the first author of this technical note. This computer program uses the finite strain consolidation theory, a secondary compression model based on Mesri, Lo, and Feng (1994), and an empirical desiccation model. This program can be used to estimate the remaining service life of a facility, the effect of dredging operations on storage capacity, and the effectiveness of dewatering techniques. The finite strain consolidation model, PCDDF89, is being modified to incorporate radial flow to simulate the installation of vertical strip drains.

Conclusions

Using vertical strip drains to consolidate dredged fill and soft foundation soils will significantly increase the consolidation rate, resulting in a corresponding rapid increase in storage capacity and soil shear strength. The strength gain will allow perimeter dikes to be constructed to higher elevations without setbacks or stability berms.

The installation of vertical strip drains will reduce the height of existing management areas, possibly allowing a new management area to be constructed on top of the existing area. The installed strip drains also will accelerate consolidation of the existing dredged fill and foundation clay as new dredged material and perimeter dikes are placed. Strip drains have also been proposed to consolidate inactive management areas for future development.

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